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U.S. ARMY
TACOM

Feasibility of Using a Large Press (80,000 - 200,000 Ton) for Manufacturing Future Components on Army Systems

Contract No. DAAE07-83-M-R028

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NOTICES

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This report summarizes the findings of a study on the potential use of a large press, larger than 50kt, for manufacturing components of the present and future Army Systems. Specifically, the report covers:

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(a) The technical background on and present status of large press forging technology.

(b) The summary and highlights of visits made throughout this study.

(c) Other contacts and information sources utilized in the study.

(d) Example parts that can be considered for forming/forging in large presses.

(e) Potential use of flexible tooling to form armor plate.

The conclusions are summarized as follows:

(1) Concerning present and future forged components, the Army does not appear to have a need for a press larger than the presently available 50kt presses.

(2) Concerning components or subassemblies made by welding from Al or armor steel plate, there is a potential for using a large press (50kt to 80kt) for making these components by forming from thick plate. However, before this potential can be realistically considered, it is necessary to establish that (a) subassemblies from plate can be formed to achieve desired tolerances and properties and (b) the plate forming technique is cost competitive. Thus, additional technical and cost-related studies will be necessary to explore the practicality of plate forming technique as a competitive production process.

PREFACE

This report covers the work performed under Contract No. DAAE07-83-M-R028 from February 18, 1983 to June 18, 1983. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Army. This contract with Battelle Columbus Laboratories, Columbus, Ohio, was initiated under the project "Feasibility of Using a Large Press (80,000 - 200,000 ton) for Manufacturing Future Components on Army Systems". It has been conducted under the direction of Ms. Janet Dentel, DRSTA-RCKM of TACOM. At Battelle the project was conducted by Dr. Taylan Altan, Senior Research Leader, and Dr. Lee Semiatin, Principal Research Scientist, with assistance from Mr. Tom Byrer, Manager of Metalworking Section. Various individuals interviewed throughout this project contributed significantly to the project progress and provided very important data and information. They are acknowledged in appropriate sections of this report. However, the authors accept sole responsibility for the conclusions and recommendations made as a result of this study.

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1.0. INTRODUCTION AND SUMMARY

Various DoD agencies, notably the US Air Force, the US Navy and the US Army, are investigating the feasibility and cost effectiveness of building large presses, up to 200,000 ton load capacity. Some studies[1,2*] indicate that such large presses may represent a potentially valuable capability for producing large components for DoD systems of the 1990's and beyond. Production of large integral parts by forging and forming is expected to save assembly costs and reduce weight in aerospace systems.

Large presses, up to 50k ton load capacity, are available in the US today. This study was conducted in order to establish, from an objective and technical point of view, the needs of the US Army concerning the potential use of a press larger than 50k ton capacity. The findings of this study can be summarized as follows in terms of current and future Army needs:

		Current	Potential
(1)	Forging		
	Tanks/vehicles	50kt or less	50kt or less
	Helicopters	50 kt	50kt, possibly larger
(2)	Forming		
	Steel or Al Plate	less than 15kt	Possibly up to 80kt

It should be noted that at this time plate forming is not a production process. The projections for plate forming, made above, are based on three major assumptions:

- o Technical feasibility of forming 4340 steel, Al 5083 and Al 7039 plate is established.
- o In case of the armor steel plate assemblies (M-1), the formed plate can be formed at hardened condition or can be heat treated to have the required ballistic properties and hardness (30 - 32 R_c).
- o The plate forming and heat treating combination is cost competitive compared with present techniques.

Thus, additional technical and cost-related studies are necessary to establish the validity of the assumptions listed above. In this regard, the concept of a flexible forming tooling, developed originally in Japan for forming compound curvature ship plates, should be considered. This concept, discussed later in this report, has the potential of reducing tooling costs and offering a flexible manufacturing capability not only for Army but also for selected Navy and Air Force hardware.

In summary, the findings of this study are:

*Superscripts refer to references, given at the end of this report.

(1) The U.S. Army does not need, now and in the future, any press with a capacity larger than 80kt.

(2) Presses larger than 50kt can be used for plate forming. However, in this case, R & D is necessary to assure that forming armor plate is a production process.

2.0. OBJECTIVES AND SCOPE

The overall objective of this study is to determine the most appropriate press capacity for forging or forming present/future US Army System Components that may use large integral forged/formed parts.

This objective has been achieved by conducting the following tasks:

- Meet with TACOM representatives and with major Army contractors to identify present/future Army systems that may use large integral forged/formed parts.
- Review designs with major Army contractors to evaluate present/future systems to determine which are potential candidates for forging with a large press.
- Assess alternative technologies such as P/M forging, warm forging and cold coining, that may be able to produce large components, greater than or equal to 1,000 square inch plan area.
- Investigate the future availability of ancillary equipment/facilities that are necessary for operating a large press, e.g., die block suppliers, die sinking capability and heat treatment facilities.

3.0. BACKGROUND

Before summarizing the results of the visits, discussions and reviews made in this study, it is useful to review, briefly, the present status of very large presses and their use in the US and abroad.

3.1. Large Presses in the US

The two largest presses in the US are hydraulic presses rated at 50,000 tons and are located (a) at the Alcoa plant in Cleveland, Ohio, and (b) at the Wyman-Gordon plant in North Grafton, Massachusetts. The specifications of the seven largest hydraulic closed die forging presses located in the US are given in Table 3-1[3]. All these presses are

Table 3-1. Specifications of the Seven Largest Hydraulic Forging Presses Located in the United States[3]

Press Capacity, tons	Builder	Press Dimensions, feet			Maximum Ram Speed, in./min		Location	Remarks
		Bed	Daylight	Stroke	Approach	Pressing		
50,000	Loewy	12 x 32.5	~14	6	480	~120	Wyman-Gordon North Grafton, Massachusetts	Pull-down, laminated plate and link pin design.
50,000	Mesta	12 x 24	15	6	180	~120	Alcoa, Cleveland, Ohio	Push-down, 8 cylinders 8 tie-rod columns.
35,000	Loewy	12 x 30.5	~12	6	480	~150	Wyman-Gordon North Grafton, Massachusetts	2 side rams, 3,000 tons each.
35,000	United	12 x 24	15	8	300	~150	Alcoa, Cleveland, Ohio	Push-down, 8 cylinders 8 tie-rod columns.
35,000	Cameron	10 x 10	25	12	400	~120	Cameron Iron Works, Houston Texas	Pull-down, laminated plate with link pin, 4 cylinders
20,000	Cameron	12 x 12	14	7	300	~ 60	Cameron Iron Works, Houston Texas	Laminated plate and link pin, push-down, 2 side rams, 7500 tons each.
18,000	Mesta	7 x 12	10.5	5	200	150	Wyman-Gordon North Grafton, Massachusetts	Push-down, 4 cylinders, 4 tie-rod columns.

accumulator driven, therefore, the exact ram speed is also influenced by (a) the actual forging load exerted against the ram and (b) the amount of ram travel necessary under load. Consequently, the load and velocity specifications, listed in Table 3-1, give only the nominal range. The press bed sizes of the world's four largest presses are given in Figure 3-1[4].

The speed characteristics of a hydraulic press are extremely important because the ram speed of the press influences the contact time between the deforming metal and the dies. In cases where the forging temperature is much higher than that of the dies, for example in forging steels and titanium alloys, the long contact time results in excessive heat loss from forging to the dies. Thus, the cooled forging is more difficult to deform and requires higher forging load than in the case where the forging does not loose much temperature during the forging stroke. The consideration of the influence of press speed upon (a) instantaneous forging temperature and (b) required forging load illustrates that not only the nominal press load capacity but also the press ram speed determine how well (to what extent of forging geometry definition) a part can be forged in a given press.

3.2. Large Presses Abroad

The three largest presses of the world are designed and built by the Soviet Union. Of these, two have 75,000 metric ton (82,500 US tons) capacity and are located in the Soviet Union. The third is the largest press of the free world and has a capacity of 65,000 metric tons (71,500 US tons). It is located at Interforge in Issoire, France. (Interforge is a consortium supported by four French companies: Forgeal of Pechiney Ugine Kuhlmann Group, Creusot-Loire, Aubert et Duval, and Snecma). The significant characteristics of this press are[5]:

Maximum Press Force	65,000 metric ton (71,500 US tons)
Working Pressure	5 KSI and 10 KSI
Force of Piercing Cylinder	13,500 metric ton (14,850 US tons)
Bed Size	3.5 m x 6 meter (140 x 240 in.)
Day Light	4.5 meter (175 in.)
Stroke	1.5 meter (60 in.)
Ram Speed	2 to 50 mm/sec (0.08 to 2 in./sec)

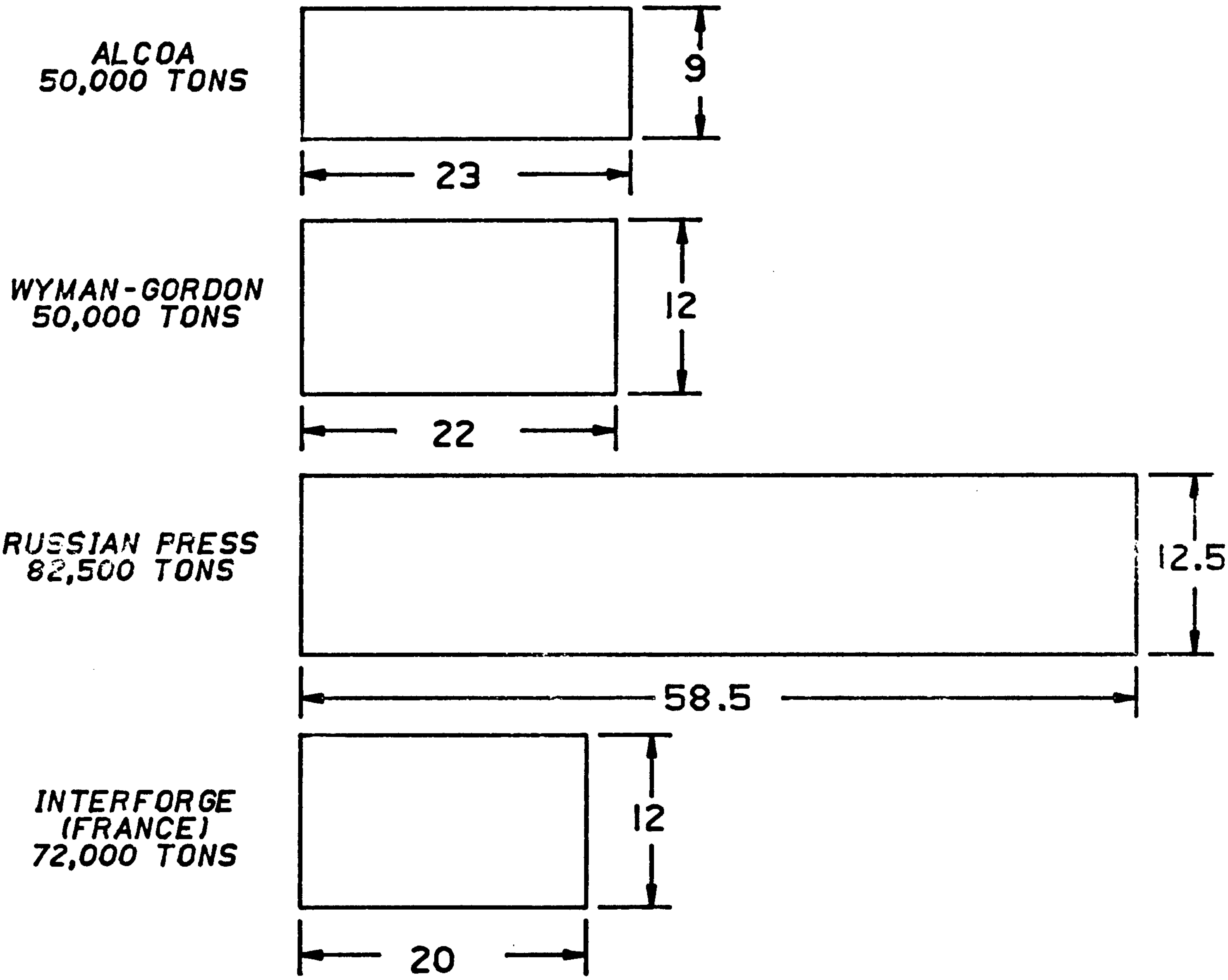


Figure 3-1. Bed Sizes of the World's Four Largest Hydraulic Presses (Dimensions are in foot)

This press is primarily used for hot forging of aluminum and titanium alloys and steels and for cold coining (stress relieving) of aluminum forgings. It is reported that more than 50 percent of the forged parts are for the aerospace industry while about 75 percent are from Al alloys. Approximately two thirds of the parts forged in this press use the capacity range between 25,000 to 40,000 metric tons while one third of the forged parts uses the press capacity range between 40,000 to 65,000 metric tons.

4.0. SUMMARY OF VISITS

As part of this study several phone contacts and a few visits were made. The important aspects of these visits are summarized below:

4.1. General Dynamics Corporate Headquarters St. Louis, Missouri (January 13, 1983)

The following people were met:

- Mr. Henry Johnson, AFWAL
- Ms. Veronica Bloemer, AFWAL
- Mr. J. E. Gagorik, NAVSEA
- Dr. A. M. Lovelace, VP, Productivity, General Dynamics
- Dr. L. F. Buchanan, VP, Engineering, General Dynamics
- Mr. C. Claysmith, Corporate Director, R & D, General Dynamics
- Mr. M. McKelvie, AVRADCOM

The highlights of this visit are:

- A presentation was made by Mr. Johnson on the latest status of the heavy press study conducted by the JLC Ad Hoc subpanel members[4].
- A detailed study conducted by Aerospace Industries Association shows that if a 200,000 ton capacity press were available, considerable savings could be achieved with aerospace forgings alone (about $1.3 billion over 20 years)[1]. This study also indicates that the percentage of potential forgings that are required in future aerospace systems and that can be made in a large press increases considerably with increasing press capacity. This is seen in Figure 4-1[1].

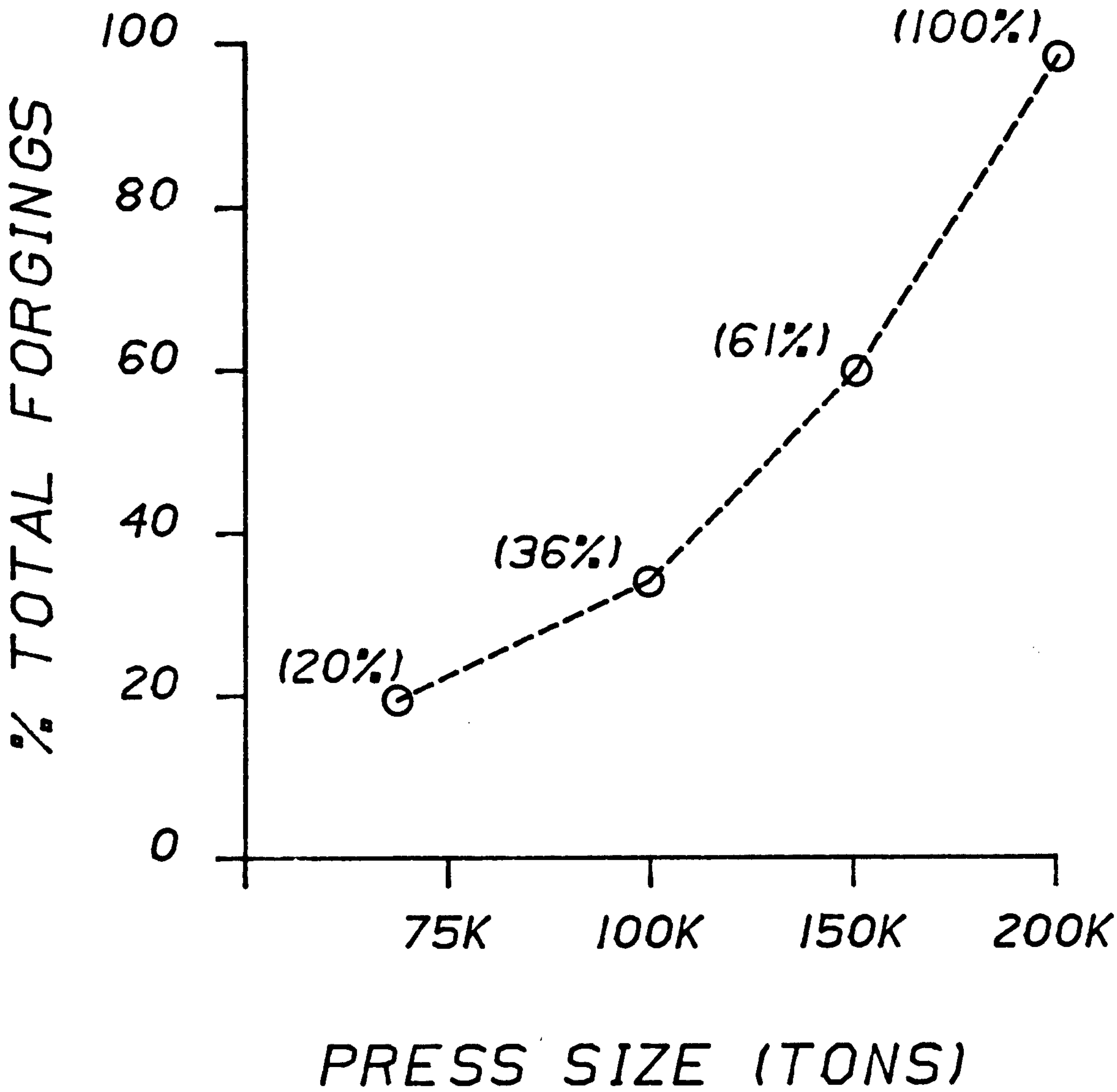


Figure 4-1. Percent of Total Aerospace Forgings Accommodated by Presses of Various Load Capacity[1]

- Emerging technologies such as powder metallurgy, composites, isothermal forging, superplastic forming/diffusion bonding, advanced casting and welding are not expected to replace large forgings (requiring 50,000 ton or larger press capacity) that are used in aerospace industry.

- Aerospace needs and justification for a large press appear to be well documented. An Army system that may have potential parts for larger presses is the M-1 tank built by General Dynamics.

4.2. TACOM, Warren, Michigan (March 21, 1983)

This visit was coordinated by the TACOM program manager, Jan Dentel.

The following people were met:

- Ms. Jan Dentel, DRSTA-RCKM, Program Manager

- Col. Herbert Dobbs, Chief of Systems and Technical Planning Office

- Col. Thomas Huber, Chief, Tank Automotive Systems Laboratory

- Mr. Robert Culling, DRSTA-TRP

- Mr. I. Binder, DRSTA-GBM

- Mr. Ted Puuri, DRSTA-ZED

- Mr. Sam Goodman, DRSTA-RCKA

- Mr. George McAllister, DRSTA-RCKM

- Mr. Don Cargo, DRSTA-RCKM

The highlights of this visit are:

- Very valuable information and suggestions were provided by TACOM staff.

- Future Tanks and Infantry Fighting Vehicles are not expected to be larger in size.

- The M-1 tank (General Dynamics) consists of many welded assemblies from armor steel that could be possibly formed or forged in integral form.

- The M-2 and M-3 (FMC) IFV's consist of welded aluminum alloy plates and also have a few large forgings.

- Visits should be made to G-D and FMC plants.

4.3. <u>General Dynamics, Land Systems Division Lima, Ohio (March 30, 1983)</u>

The following people were met:

- Mr. Mark Stein, Manager, Manufacturing Development and Support

- Mr. Milton F. Snyder, Chief, Manufacturing Development and Support

- Lt. Col. Joseph Mayton, Plant Commander (phone contact only)

The highlights of this visit are:

- A plant tour helped to visualize and identify some of the M-1 subassemblies. Messrs. Stein and Snyder also sent later to Battelle additional drawings on various parts and subassemblies.

- A large number of individual parts are flame cut from plate, deburred and welded to assemblies. The material is armor plate (composition similar to 4130 and 4340) at 32-34 R_c hardness. Plate thickness varies from 0.75 - 1.5 inch to 5.5 inch.

- It is not practical to form a plate in hardened state. "Forming" must be done in "soft" state and heat treating must follow.

- Efforts are on the way to replace welded assemblies with castings or forgings whenever cost reductions are possible.

- The angles on the turret and hull are critical design angles and cannot be changed, although the sharp corners at welded joints may be modified.

- Several subassemblies are identified for potential forming or forging (the press capacities needed for these are discussed later).

4.4. FMC Corporation, San Jose, California (April 11, 1983)

FMC builds the Bradley Infantry Fighting Vehicles, M-2 and M-3. The following people were met:

- Mr. Al House, Chief Engineer, Advanced Technology and Planning
- Mr. Carl M. Hanes, Sr., Industrial Engineer
- Mr. Don Fylling, Manager, Advanced Design

The highlights of this visit were:

- Ballistic portions of the vehicle are from Al 7039, non-ballistic portions from Al 5083 (easier to machine and weld).
- FMC developed considerable know-how in welding of aluminum alloys (metallurgy as well as fixturing and automation).
- Several (15 to 20) parts are forged. Most of these are small, except one: the turret base plate that is forged in a 35,000 ton press from Al 5083.
- There are several welded subassemblies that could be hot or cold formed from plate, if feasibility and cost effectiveness are demonstrated. For the ballistic portions of the turret and hull it is also necessary to ascertain that ballistic properties (best correlated with yield strength) can be obtained.
- Forgings need long lead time and the cost per pound of a forging increases with its weight and size.
- The trend is towards smaller and lighter vehicles. Larger vehicles are not expected.
- Whether a certain subassembly should be made by forming/forging or by welding will be decided based on cost. The technology of forming/forging does not present a major problem in aluminum alloys.

4.5. Alcoa, Cleveland, Ohio (April 14, 1983)

This visit was coordinated by Mr. Henry Johnson (AFWAL). The following people were met:

- o Mr. R. M. Peters and others from Alcoa, Cleveland
- o Messrs. Alex Zeitlin and Adam Zandel, Press Technology Inc.
- o Mr. John Larry Baer, Army DARCOM
- o Mr. Robert Davies, NASA-Lewis
- o Mr. Henry Johnson and Ms. Veronica Bloemer, AFWAL
- o Mr. Joe Collins, NAVAIR
- o Mr. William T. Richards, McDonnell Aircraft

The highlights were:

- o If a large press should be built, then there should be two of them, in case one of them cannot be used for any reason.
- o Die pressures in hot forging or cold coining do not usually exceed 40 tons/sq. in.
- o In the present 50kt press, there are dies that have a plan area of the die cavity up to 6000 sq. in. At the present, the largest die has the approximate dimensions of 20 ft x 5 ft x 1.5 ft. Alcoa is today able to machine die blocks with 22 ft x 9 ft x 2 ft dimensions.
- o The cost per pound of forging is 2 to 3 times larger in larger sizes (forged in 35kt and 50kt presses) than in smaller sizes (forged in 20kt and smaller presses).
- o Approximately 10 percent of the forgings made in the 35kt and 50kt presses are for the Army programs. These include M-2 and M-3 Infantry Fighting Vehicles, M113 people mover and converted tow vehicles, AH60A, CH47, and CH54 helicopters and Pershing and Lance missiles.

- o Depending upon business conditions, the utilization rate of the 35kt and 50kt presses varied between 40 to 60 percent, over the last fourteen years.

4.6. <u>DARCOM, Washington, D.C. (May 11, 1983)</u>

This meeting was set up to review briefly the program progress. The following people were present:

- o Mr. Fred J. Michel, Director, Manufacturing Technology, DARCOM
- o Mr. John Larry Baer, Manufacturing Technology, DARCOM
- o Mr. George I. Schuck, Manufacturing Technology, DARCOM
- o Mr. H. Johnson, AFWAL
- o Mr. J. Laster, US Army, Joint Activities
- o Mr. J. Collins, NAVSEA

The highlights are:

- o Review of the program progress.
- o Discuss the preliminary conclusions of the study regarding the Army's interest and need for a large (larger than 50kt) press.

5.0. OTHER CONTACTS AND SOURCES OF INFORMATION

Throughout this study, informal contacts that Battelle has with the Forging Industry and various government agencies were used to gather additional information, relevant to this study. Among these contacts, the following organizations and individuals provided valuable assistance:

- o AMMRC, Mr. Roger Gagne. AMMRC had made an earlier study regarding the potential use of a large press for Army systems.
- o Wyman-Gordon Company (Mr. Andy McCurdy). Wyman-Gordon has, similar to Alcoa, two of the largest presses in the US (50kt and 35kt).
- o Interforge of Issoire, France (Mr. Barbazanges). This Company owns the free world's largest press (65 kt metric) that was built by the Soviet Union.

- o Forging Committee of the American Society of Metals (Chairman: Taylan Altan, Battelle-Columbus Laboratories).

The information provided by Interforge is already discussed under the BACKGROUND section, 3.0. The following is a summary of other information made available to Battelle:

- o Several titanium and aluminum alloy components (rotor hubs, transmission covers, etc) are forged in 35kt and 50 kt presses.
- o There are several parts from Al 5083 and Al 7039 that are being forged now or are being considered to be forged in the 35kt and 50kt presses.
- o In the past, a M-60 tank hull component from armor plate with a plan area of 3510 sq. in. was forged in the 50kt press on a trial basis. However, this application did not go into production.
- o The present large Army helicopters have components that are being forged in the 50kt press. However, the CH47 Modernization Office, for example, does not see any need for larger parts or press capacity for present and future components.

6.0. CANDIDATE PARTS FOR LARGE PRESSES

Through the visits made at General Dynamics' Lima plant (M-1) and FMC's Jan Jose plant (M-2 and M-3), certain parts and assemblies were identified for potential forming/forging in large presses. Due to limited time and project scope, a thorough investigation concerning technical feasibility (obtaining of geometry without defects and ballistic properties) and cost competitiveness (vs present welding assembly techniques) could not be made. Nevertheless, these parts are listed in Table 6-1. The methods of calculating the forming loads are given in Appendix A. Flow stress data, used in these calculations, are summarized in Appendix B. All of the parts are presently made from armor materials by welding a number of plates to assemble the desired final configuration.

Alternative manufacturing processes for the parts listed in Table 6-1 would include prototype metalforming operations such as deep drawing (Part Nos. 1 and 9) and U-bending (Part Nos. 2 through 8) in a suitable hydraulic press. For all of these parts except No. 9, it is seen that the maximum press capacity required is only about 12.5kt (See Appendix A). This is true whether the armor materials are formed in the hardened or annealed (soft) conditions at room temperature or at hot forming temperatures.

Table 6-1. Candidate Parts for Press Forming (Estimated Loads are in Tons)

Part Number	Company	Part Name (Vehicle)	Material	Prototype Forming Operation	Estimated Press Load(t) R.T., Hardened Plate(a)	R.T., Annealed Plate(b)	Hot Forming Temperature(c)
1	FMC	Turret/Back Half (M2/M3)	Al Armor Plate (5083)	Deep Draw	12,600	6,300	4,900
2	FMC	Front Plate Assembly (M2/M3)	Al Armor Plate (5083)	U-Bend	9,400	4,700	3,650
3	GD	Turret Roof (M1)	Steel Armor Plate (R_c 32-34)	U-Bend	4,900	3,650	550
4	GD	Left Side/Turret (M1)	Steel Armor Plate (R_c 32-34)	U-Bend	3,800	2,800	450
5	GD	Bustle/Turret (M1)	Steel Armor Plate (R_c 32-34)	U-Bend	1,000	700	100
6	GD	Subassembly 15000134-LH Driver Wall (M1)	(Steel Armor Plate (R_c 32-34)	U-Bend	450	300	50
7	GD	Subassembly 1500049-Torsion Bar Cover (M1)	Steel Armor Plate (R_c 32-34)	U-Bend	1,000	750	100
8	GD	Subassembly 1500093-RH Driver Compartment (M1)	Steel Armor Plate (R_c 32-34)	U-Bend	750	550	100
9	GD	"Bottom Assembly" (M1)	Steel Armor Plate (R_c 32-34)	Deep Draw	81,500	60,500	9,300

(a) Based on σ = 90 KSI (5083 in hardened condition)
σ = 175 KSI (Steel Armor plate, R_c 33)

(b) Based on σ = 45 KSI (5083 in annealed condition)
σ 130 KSI (Steel Armor plate in spheroidized annealed condition)

(c) Based on σ = 35 KSI (5083, T = 500F)
σ 20 KSI (Steel Armor plate, 1900F)

This conclusion is based on the fact that most of the parts can be made via bending, an operation involving relatively small loads.

For Part No. 9, required press loads are much higher. This part is the monolithic equivalent of the bottom shell of the M-1 tank and is assumed to be approximately in the form of a rectangular pan whose sides measure 310 and 155 inches and whose wall thickness is 1 inch. It is seen from Table 6-1 that the required load, if the armor steel is formed in the hardened condition (R_c 33), would be of the order of 80kt. Even if it were in the soft, annealed condition, in which the ductility would be substantially higher, the necessary tonnage is still in excess of 60,000 for room temperature fabrication. Hence, a press of capacity larger than 50kt could possibly be used for forming this part, at least.

7.0. POTENTIAL USE OF FLEXIBLE TOOLING FOR FORMING OF ARMOR PLATE

Forming of armor plate, from aluminum alloys or from armor steel, represents a potential process for reducing manufacturing costs. The main structure of the M-1 tank (armored steel) and of the M-2 and M-3 (aluminum alloy) Armored Fighting vehicles are made by assembling of a large number of welded subassemblies. These subassemblies could conceivably be manufactured by forming from plate (cold or hot; annealed or in heat-treated condition). There is, however, virtually no experience regarding the technical practicality and the cost effectiveness of this manufacturing alternative. One major drawback can be expected to be tooling costs. These costs are considerable in forming; as a result, a very large number of parts must be produced in order to amortize the tooling costs.

One possible alternative for reducing tooling costs and for providing a technique to form thick plate (aluminum alloy or steel) is to use a "flexible die". This concept, originally developed in Japan as a press, is being used in production for forming ship plates. The schematic of this press is illustrated in Figure 7-1.

The press has thirty upper and lower punches located in three rows. The location of the upper punches are adjusted by screw drives controlled by a microcomputer. The lower punches are driven upward by hydraulic cylinders[6]. A bending operation in this press is schematically illustrated in Figure 7-2. This figure indicates the positioning of the punches for forming parts with relatively simple geometries. An extension of this design, to form more complex parts from plate, is schematically illustrated in Figure 7-3.

The "flexible die" concept could be developed further to manufacture complex parts that can replace welded assemblies in production of tanks and other armored vehicles. This forming technique could also be used in ship building and in aerospace industry. In Navy and Army applications,

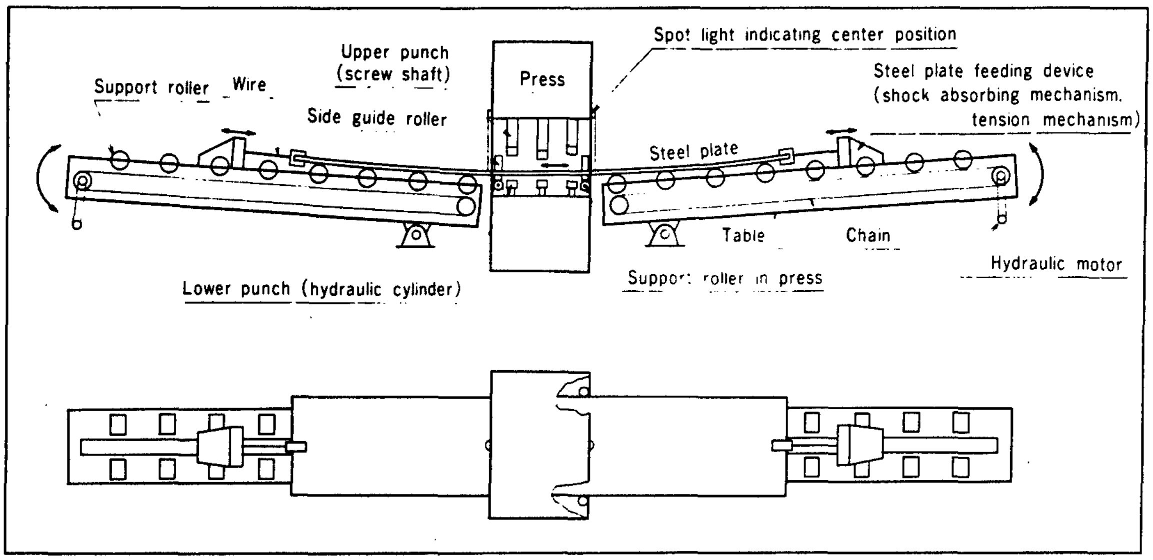


Figure 7-1. Overall Mechanism of Triple-Row-Press Including Front and Rear Conveying Tables

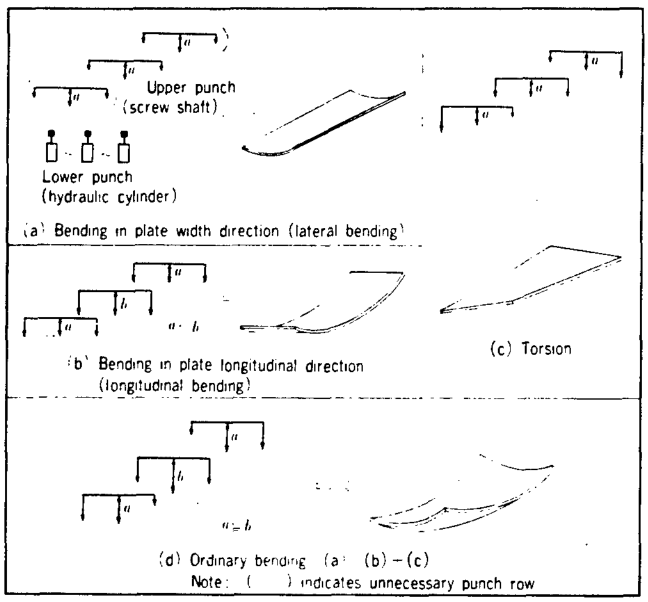
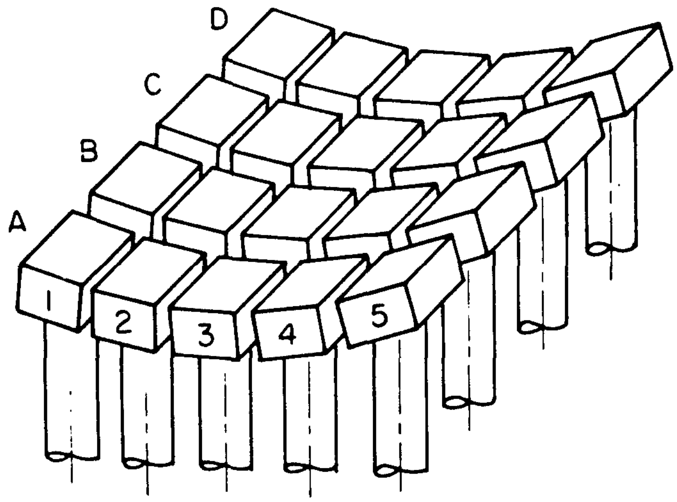
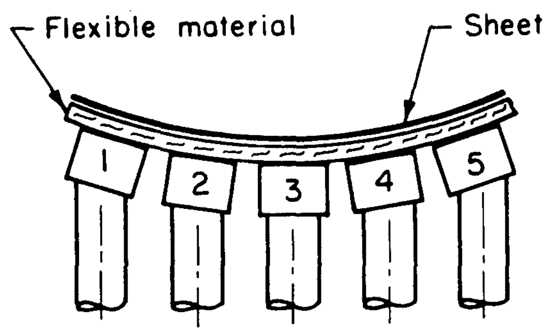


Figure 7-2. Schematic of Four Simple Bending Operations in the Triple-Row Press (or flexible tooling system)



(a)



(b)

Figure 7-3. Extension of the Triple-Row Press Design into the "Flexible Tooling" Concept
(a) Schematic of the lower "die"
(b) Possible use "flexible tooling" for forming thin sheet

most structures are made from thick plate. In aerospace applications, however, it is necessary to form thin aluminum sheet without indenting the material locally. Therefore, in this application the "flexible die" concept must be modified to have a flexible protective material (rubber or plastic) covering the individual punches and forming a smooth surface. This "flexible surface" can be modified by simply changing the position of the individual punches via computer control.

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LIST OF REFERENCES

(1) Aerospace Industries Association of America, Inc., "Survey of the Technical and Economical Utilization of a Forging Press Greater than 50,000 Tons Capacity", prepared by the Manufacturing Committee, August 1981.

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(3) Altan, T., et al, "Forging Materials, Equipment and Practices". MCIC Hand Book No. 3, 1973, Battelle-Columbus Laboratories, Columbus, Ohio 43201.

(4) Johnson, H., "Heavy Forging Press Review". Viewgraph presentation given at General Dynamics Corporate Headquarters, St. Louis, Missouri, January 1983.

(5) Barbazanges, J., "New Possibilities Offered by the Press of Interforge" (in French), Annales des Mines, January 1979, p 55.

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APPENDIX A

LOAD ESTIMATION FOR PRESS FORMING OF ARMOR PLATES

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A-1.0. LOAD ESTIMATION FOR PRESS FORMING OF ARMOR PLATES

In the section 6.0 CANDIDATE PARTS FOR LARGE PRESSES, forming loads were estimated and tabulated for a number of M-1, M-2, and M-3 parts which are presently made as welded assemblies from plate. These estimates were based on the assumption that forming would basically consist of operations such as deep drawing and U-bending, as seen in Figure A-1. The following equations were used to estimate the forming loads, P:

$$P_{drawing} = \frac{2}{\sqrt{3}} \Pi d t \sigma_{UTS} \tag{A1}$$

and

$$P_{U\text{-}bending} = \frac{Lt}{\sqrt{3}} \sigma \quad . \tag{A2}$$

In Equation (A1), the required load for deep drawing is an upper estimate based on the assumption that the vertical cup wall of diameter d and thickness t can support stresses no greater than the ultimate tensile strength, σ_{UTS}. If the drawn part is not cylindrical, as postulated in Equation (A1), a similar formula is used in which Πdt is replaced by the area of a cross-section through the vertical wall of the part, which supports the load.

For U-bending, the load predicted by Equation (A2), in which L denotes the plate depth and t its thickness, is also an upper estimate for bending in which the part is coined at the end of the stroke. Here, σ is an average flow stress of the material being formed.

The dimensions d, L, and t used in calculating the loads for the various parts given in Table 6-1, are summarized in Table A-1. These dimensions were liberal estimates taken from prints such as those in Figures A-2 through A-7 for Part Nos. 3 through 8, respectively. Further, stress σ_{UTS} for use in Equation (A1) was taken as being equal to the average flow stress σ in all cases since the materials studied exhibit rather low levels of work hardening. The flow stresses themselves were obtained from various handbooks and unpublished Battelle data (see Appendix B).

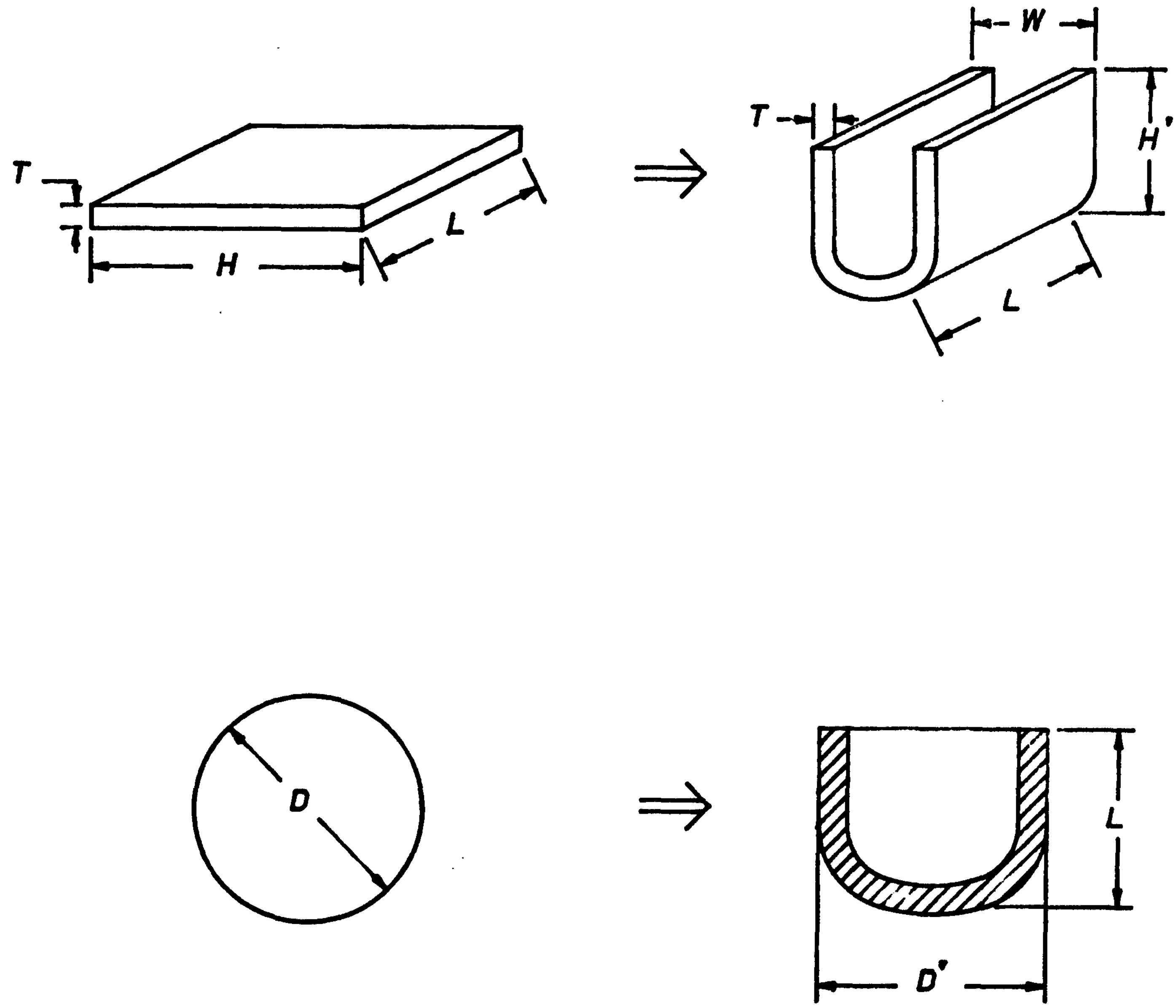

Figure A-1. Prototype Forming Operations for Armor Plate

Table A-1. Dimensions Used in Load Estimation for Deep Drawing and U-Bending of Armor Plate

Part No.[a]	Type of Forming Operation	d(in.)	L(in.)	t(in.)
1	Deep Draw	51.5	---	1.5
2	U-Bend	--	240	1.5
3	U-Bend	--	97	1.0
4	U-Bend	--	30	2.5
5	U-Bend	--	50	0.375
6	U-Bend	--	34	0.25
7	U-Bend	--	80	0.25
8	U-Bend	--	58	0.25

See Table 6-1. for Part Name, Manufacturer, and Material

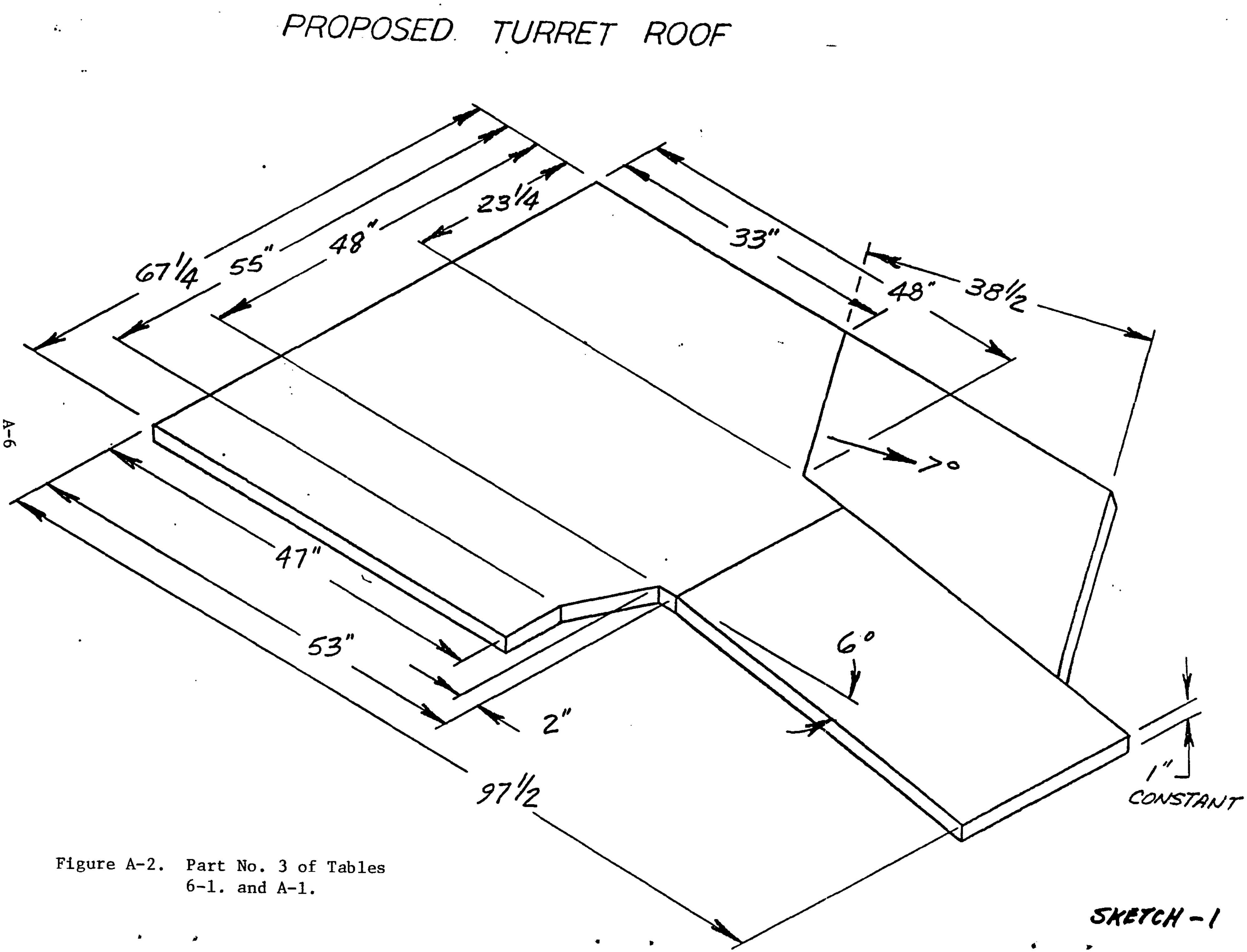

Figure A-2. Part No. 3 of Tables 6-1. and A-1.

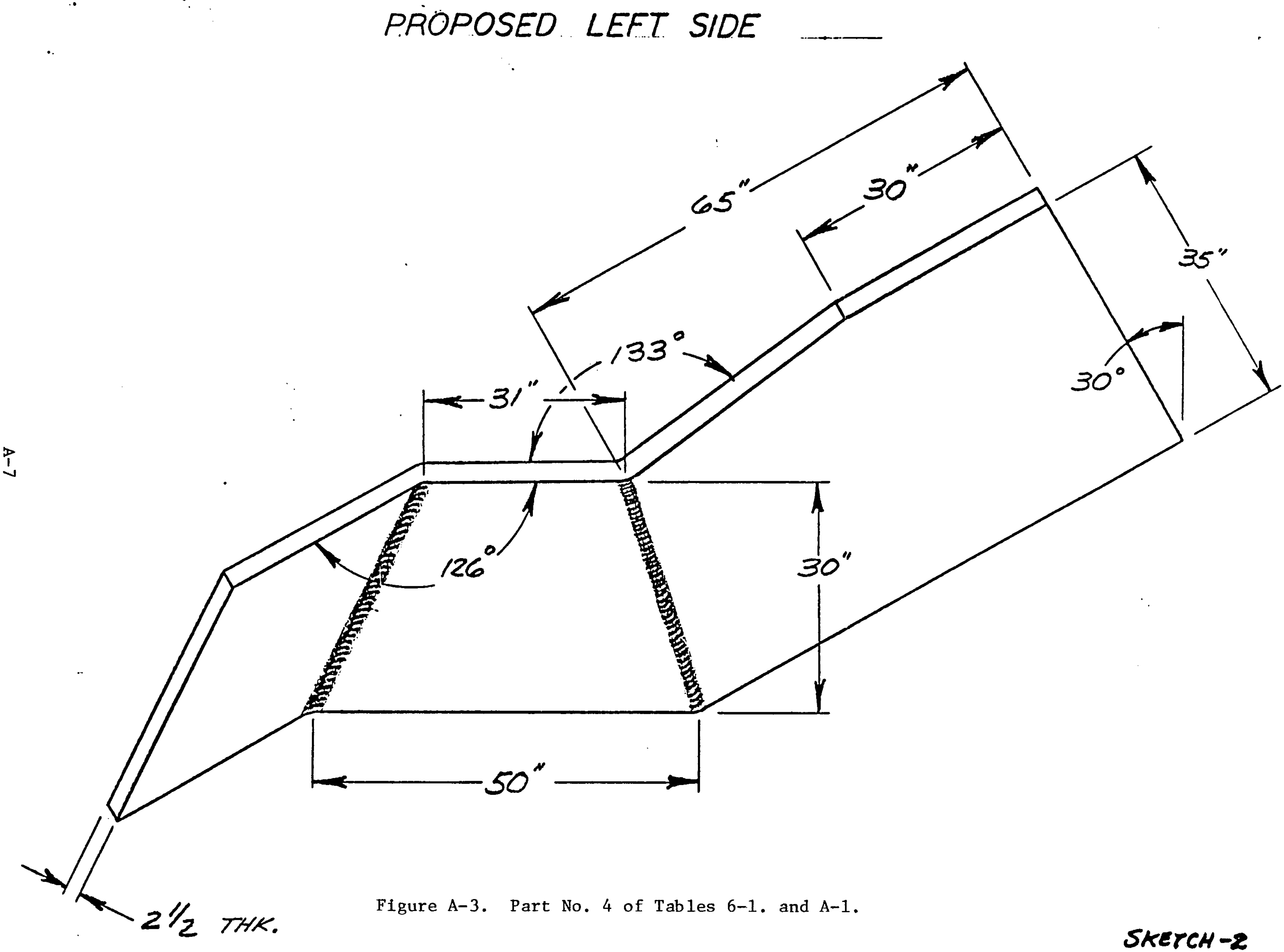

Figure A-3. Part No. 4 of Tables 6-1. and A-1.

SKETCH-2

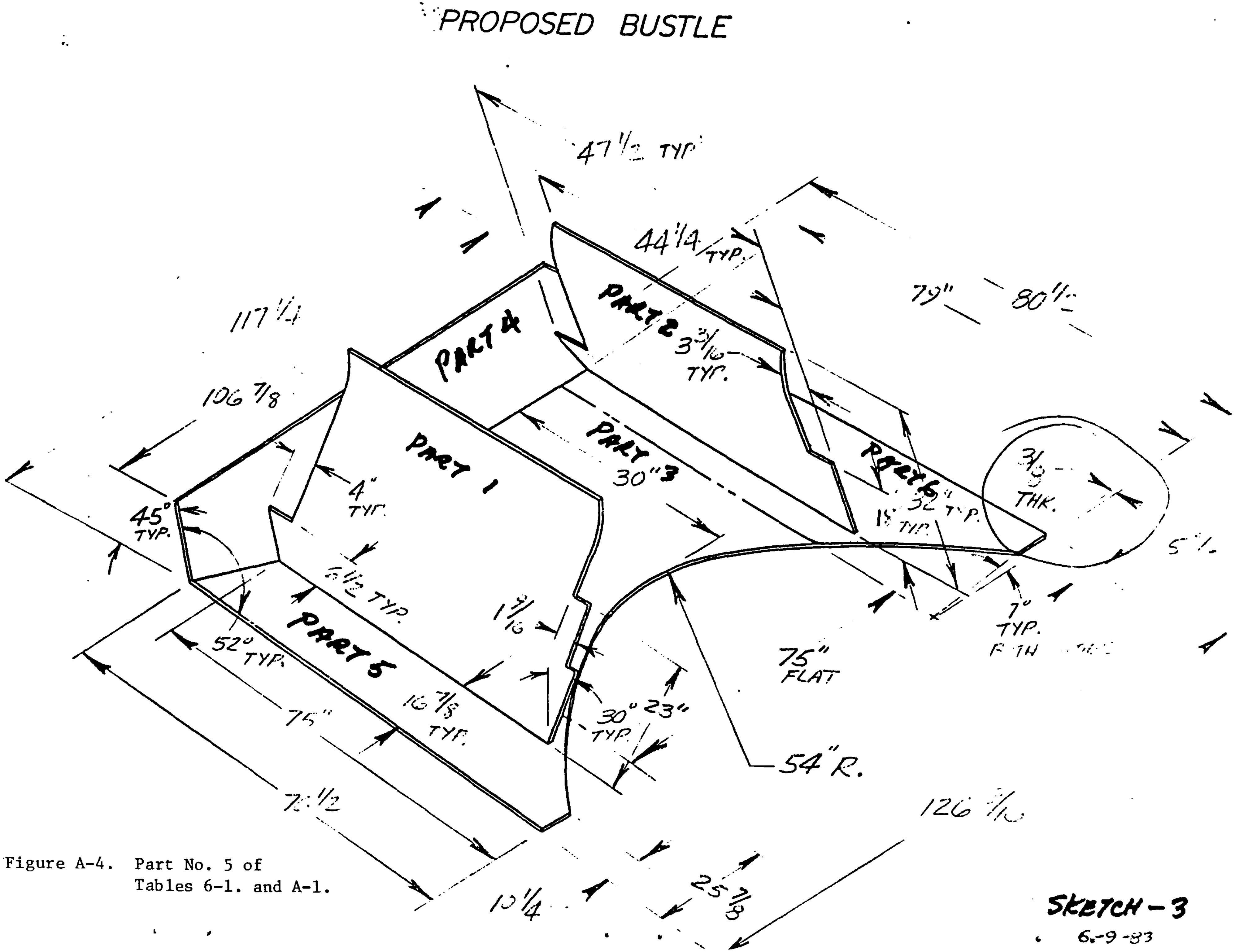

Figure A-4. Part No. 5 of
Tables 6-1. and A-1.

WELDMENT ISOMETRIC: IDENTIFYING SIZE, JOINT CONFIGURATION AND LOCATION OF WELD(S)

APPLICABLE WELDING PROCEDURE(S)
WP-001(.035)*

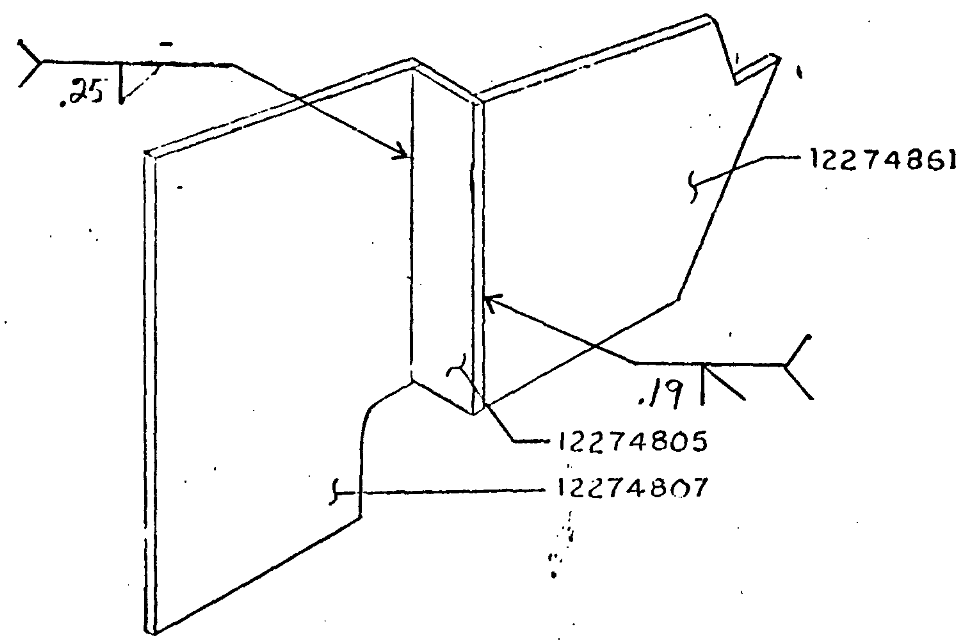

Figure A-5. Part No. 6 of Tables 6-1. and A-1.

WELDMENT ISOMETRIC: IDENTIFYING SIZE, JOINT CONFIGURATION AND LOCATION OF WELD(S)	APPLICABLE WELDING PROCEDURE(S) WP001 (0.062)

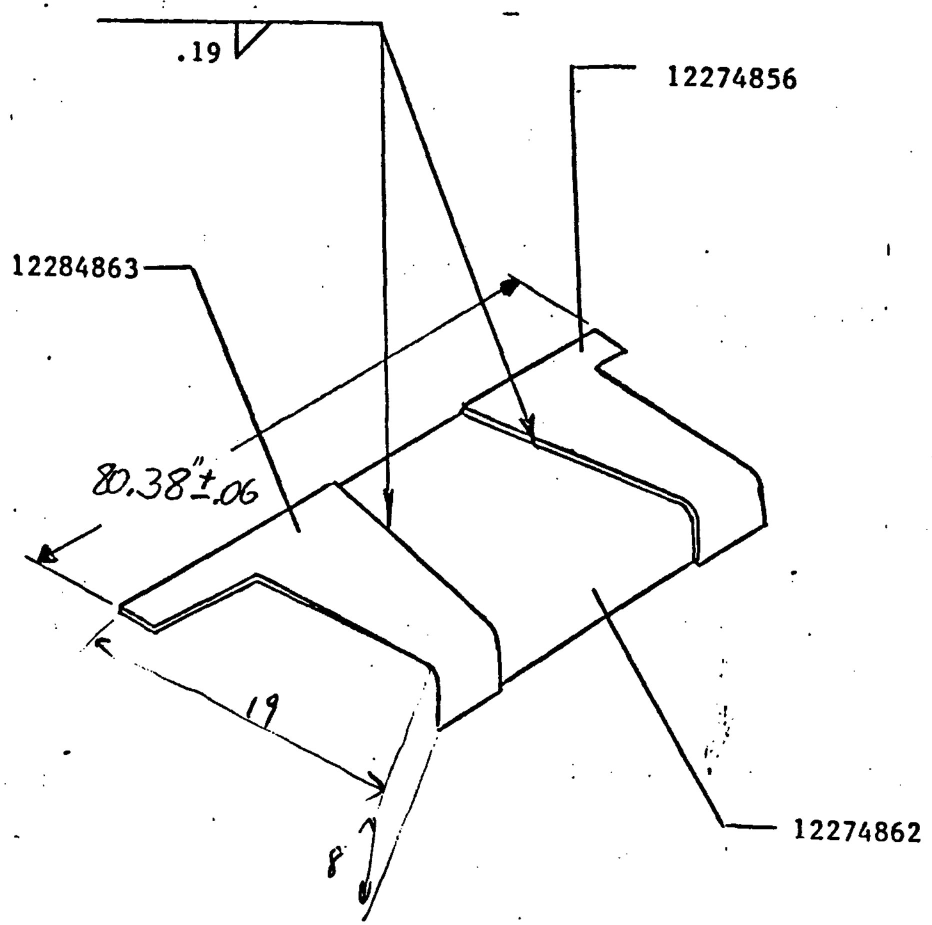

Figure A-6. Part No. 7 of Tables 6-1. and A-1.

WELDMENT ISOMETRIC: IDENTIFYING SIZE, JOINT CONFIGURATION AND LOCATION OF WELD(S)	APPLICABLE WELDING PROCEDURE(S)
	WP-001 (.035)

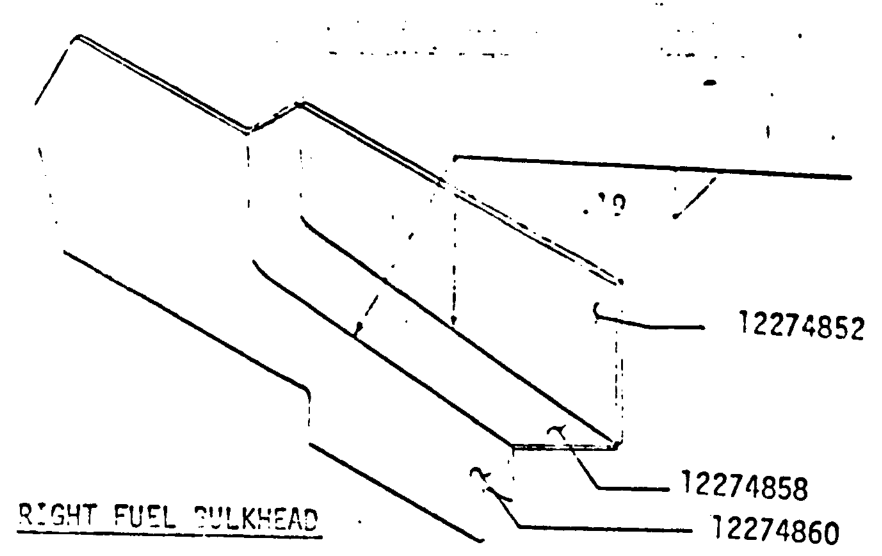

Figure A-7. Part No. 8 of Tables 6-1. and A-1.

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APPENDIX B

FLOW STRESS DATA USED FOR ESTIMATING PRESS LOADS

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B-1.0. FLOW STRESS DATA USED FOR ESTIMATING PRESS LOADS

The use of the equations for predicting forming loads requires the knowledge of the flow stress of the material as well as the geometry of the part to be formed. In this Appendix, flow stress data from various sources are summarized for purposes of documentation and to show how the average values used for calculations were obtained.

B-1.1. Flow Stress Data for Aluminum Alloys

The following data were obtained from the literature:

- 5083-0[1]
  Average Flow Stress at Room Temperature: 45 KSI
  Ultimate Tensile Strength at Room Temperature: 44 KSI
  Average Flow Stress at 500F: 38 KSI

- 7039-T6[2]
  Ultimate Tensile Strength at Room Temperature: 90 KSI

- 7049-T6[3]
  Flow Stress at 500F ≈ 1/3 Flow Stress at Room Temperature

From the above, the following were concluded to be reasonable values for estimating press loads:

σ = 90 KSI (Room temperature, hardened condition)
σ = 45 KSI (Room temperature, annealed condition)
σ = 35 KSI (500F, i.e., at hot-working temperature)

B-1.2. Flow Stress Data for Steel

The following data were obtained by the literature:

- Rolled homogeneous armor, R_c 33[4]
  Average Flow Stress at Room Temperature: 190 KSI

- 4130[3,5]
  Average Flow Stress at Room Temperature (R_c 23.5): 160 KSI
  Average Flow Stress at Room Temperature (R_c 33): 175 KSI

- 4140[1]
  Average Flow Stress at Room Temperature (Spheroidized Annealed Condition): =130 KSI

- 4340[1,3,6]
  Average Flow Stress at Room Temperature (R_c 26) : 147 KSI
  Average Flow Stress at Room Temperature (R_c 34) : 165 KSI
  Average Flow Stress at Room Temperature (R_c 39) : 198 KSI
  Average Flow Stress at 1900F : 20 KSI

From the above, the following were concluded to be reasonable values for estimating press loads during forming of steel armor plate:

σ = 175 KSI (Room Temperature, R_c 33)
σ = 130 KSI (Room Temperature, Spheroidized Annealed)
σ = 20 KSI (1900F)

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